Direct Tire Pressure Monitoring System using Pressure and Temperature Sensor

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A Design Report Submitted to the School of Electrical Engineering, Electronics and Communications Engineering, and Computer Engineering in Partial Fulfillment of the Requirements for the Degree

Bachelor of Science in Computer Engineering

Mapua Institute of Technology
September 2008

Approval Sheet

Mapua Institute of Technology
School of EE – ECE – CoE

This is to certify that we have supervised the preparation of and read the design report prepared by **Romnick B. Alegonza, Michelle Anne L. Bocado and Marvin Allan L. Lu** entitled **Direct Tire Pressure Monitoring System** and that the said report has been submitted for final examination by the Oral Examination Committee.

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ACKNOWLEDGMENT

The design team would like to express their gratitude to all those who gave them the opportunity to complete this Design Project, their family whose unconditional love and understanding have inspired them, their friends who supported and encouraged them through their advises, their Panelists and Chairman, Engr. Meo Vincent Caya, Engr. Isagani Villamor, Engr. Mary Ann Joaquin and Engr. Noel Linsangan who have shared their expertise time and guidance to improve the manuscript, their Adviser Engr. Jocelyn Villaverde, who has given them professional advices for the success of this study.

Most especially, the design team would like to express their sincere thanks to the Lord Almighty, who has given them the strength to carry on.

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ABSTRACT

Incorrect tire inflation and high tire surface temperatures are hazards to the safety to all those traveling the highways. To combat this problem, the design team built a system that will monitor the pressure and temperature of an automobile tire. All measurements will be taken by battery-powered sensors attached directly to the tire, and then transmitted by digital signal to a receiver a short distance away inside the wheel well. This accommodates the use of four tires in the system. The data will then be interpreted by a microcontroller and displayed on LEDs and 7-segment display in such a way the driver can easily identify problems with his or her tire system. Ease of use and understanding will create a system that will minimize some of the possible dangers drivers face on the road each day regarding flat-tires or over-pressured tires.

Keywords: Tire Pressure, Safety, Flat-tire, Over-pressured tire

Chapter 1

DIRECT TIRE PRESSURE MONITORING SYSTEM BACKGROUND AND INTRODUCTION

Research Setting

Tires are among the most important features on a vehicle. However, proper tire maintenance is an important safety function that is often neglected. The importance of properly maintaining the tires cannot be overemphasized. Tires are the only contact between the vehicle and the road. The tire's pressure if not checked would be risky and dangerous but checking it every time would be a hassle. With this insinuation, the group comes to a decision of constructing a system inside a car which monitors the pressure of the tire whether it is in proper condition or not.

Review of Related Literature

Ideal Gas Law

The Ideal gas law is the equation of state of a hypothetical ideal gas, first stated by Benoît Paul Émile Clapeyron in 1834.

The state of an amount of gas is determined by its pressure, volume, and

temperature according to the equation:

$$PV = nRT$$

where

P is the absolute pressure of the gas,

V is the volume of the gas,

n is the number of moles of gas,

R is the universal gas constant,

T is the absolute temperature.

The value of the ideal gas constant, *R*, is found to be as follows:

$$\begin{aligned}
R &= 8.314472 && \text{J·mol}^{-1}\text{·K}^{-1} \\
&= 8.314472 && \text{m}^3\text{·Pa·K}^{-1}\text{·mol}^{-1} \\
&= 8.314472 && \text{kPa·L·mol}^{-1}\text{·K}^{-1} \\
&= 0.08205746 && \text{L·atm·K}^{-1}\text{·mol}^{-1} \\
&= 62.36367 && \text{L·mmHg·K}^{-1}\text{·mol}^{-1} \\
&= 10.73159 && \text{ft}^3\text{·psi·°R}^{-1}\text{·lb-mol}^{-1} \\
&= 53.34 && \text{ft·lbf·°R}^{-1}\text{·lbm}^{-1} \text{ (for air)}
\end{aligned}$$

The ideal gas law mathematically follows a statistical mechanical treatment of primitive identical particles (point particles without internal

structure) which do not interact, but exchange momentum (and hence kinetic energy) in elastic collisions.

Since it neglects both molecular size and intermolecular attractions, the ideal gas law is most accurate for monoatomic gases at high temperatures and low pressures. The neglect of molecular size becomes less important for larger volumes, i.e., for lower pressures. The relative importance of intermolecular attractions diminishes with increasing thermal kinetic energy i.e., with increasing temperatures. More sophisticated equations of state, such as the van der Waals equation, allow deviations from ideality caused by molecular size and intermolecular forces to be taken into account. *(**Newtonian Physics, 2005** by Benjamin Crowell)*

Air Pressure, Temperature Fluctuations

The air pressure inside the tires supports the weight of the car. Maintaining sufficient air pressure is required if tires are to provide all of the handling, traction and durability of which they are capable.

The tire pressure recommended in a vehicle's owner's manual or tire information placard is the vehicle's recommended cold tire inflation pressure. This means that it should be checked in the morning before driving it more than

a few miles, or before rising ambient temperatures or the sun's radiant heat affects it. Since air is a gas, it expands when heated and contracts when cooled.

The rule of thumb is for every 10° Fahrenheit change in air temperature, tire's inflation pressure will change by about 1 psi (up with higher temperatures and down with lower). *(**Tire Inflation, 2008** by Larry Carley)*

Environmental Factor

In most parts of North America, the difference between average summer and winter temperatures is about -50° Fahrenheit which results in a potential loss of about 5 psi as winter temperatures set in. Meanwhile, in normal weather, the sun also affects the temperature of the tires. If the vehicle is parked in the sun, the sun's radiant heat will artificially and temporarily increase tire pressures. *(**Tire Inflation, 2008** by Larry Carley)*

Recommended Tire Pressure

Many people neglect a very important aspects of the car; its tires, which are as important as cars are. The tires on a car rotate on the ground without slipping, creating a driving force due to the friction between the tire and the ground.

One thing that is important for proper driving conditions is proper tire inflation and pressure. The ideal range of pressure in cars is between 193-234 in kPa (kilopascal) or 28 to 35 psi (pounds per square inch). *(**Tire Inflation, 2008** by Larry Carley)*

Transducer

A transducer is a device, usually electrical, electronic, electro-mechanical, electromagnetic, photonic, or photovoltaic that converts one type of energy or physical attribute to another for various purposes including measurement or information transfer (for example, pressure sensors).

The term transducer is commonly used in two senses; the sensor, used to detect a parameter in one form and report it in another (usually an electrical or digital signal), and the audio loudspeaker, which converts electrical voltage variations representing music or speech, to mechanical cone vibration and hence, vibrates air molecules creating acoustical energy.

A transducer is useful in transferring energy without using wires. It is also helpful in receiving signal from moving object, like wheel, into another device. (***Newtonian Physics, 2005*** *by Benjamin Crowell*)

Digital pressure gauge

A tire pressure gauge is adapted to measure the air pressure of a tire while an extinguisher gauge is adapted to measure the internal pressure of a fire

extinguisher. Regular pressure gauges include two types, i.e., one without liquid and the other with liquid (oil-filled). A pressure gauge generally consists of a spring element and a measuring or sensor device. The primary sensing element of the gauge typically comprises a Bourdon tube that incurs a predictable displacement in response to pressure changes to which it is exposed. Pressure gauges can generally be divided into two kinds. The first kind is a pen-type, and the other type has pressure indicator on a scale board. The value of pressures can be displayed in either digital or analogue form. A digital pressure gauge shown in Figure 1.1 generally involves the application of a microprocessor and a pressure measurement device such as a pressure sensor or load-cell coupled with a potentiometer. (*Tire Inflation, 2008* ***by Larry Carley***)

Figure 1.1. Digital Pressure Gauge

Antenna

An antenna is a transducer designed to transmit or receive electromagnetic waves. In other words, antennas convert electromagnetic waves

into electrical currents and vice versa. Antennas are used in systems such as radio and television broadcasting, point-to-point radio communication, wireless LAN, radar and space exploration. Antennas usually work in air or outer space, but can also be operated under water or even through soil and rock at certain frequencies for short distances.

Physically, an antenna is an arrangement of conductors that generate a radiating electromagnetic field in response to an applied alternating voltage and the associated alternating electric current, or can be placed in an electromagnetic field so that the field will induce an alternating current in the antenna and a voltage between its terminals.

Antenna becomes popular because of its wireless receiving capabilities. This technology is suitable in tire pressure monitoring because it can receive signal even in a rotating wheel. (*T**he Physics Factbook , An Encyclopedia of Scientific Essays 2007** by Brian Marino*)

Low Frequency

Radio frequency (RF) is a frequency or rate of oscillation within the range of about 3 Hz to 300 GHz. This range corresponds to frequency of alternating current electric signals used to produce and detect radio waves. Since most of this range is beyond the vibration rate that most mechanical systems can respond to, RF usually refers to oscillations in electric circuits or electromagnetic

radiation.

Low frequency is a type of radio frequency. The name itself sounds disadvantageous because it can only transmit from a short distance. One of the useful applications of low frequency is receiving signal from a certain area. Low frequency signal can avoid interfering with other signals. (***Vibration and Waves, 2005*** *by Benjamin Crowell*)

Thermistor

A thermistor is a type of resistor with resistance varying according to its temperature. The word is a portmanteau of thermal and resistor. Thermistors are widely used as inrush current limiters, temperature sensors, self-resetting over current protectors, and self-regulating heating elements.

Thermistor is also applicable in measuring the temperature of the tire of a car. A small-sized thermistor would be appropriate in the tire. (***Electricity and Magnetism, 2005*** *by Benjamin Crowell*)

Review of Related Studies

The design is about tire pressure monitoring using sensors to obtain data to be transmitted to the microcontroller. The same technology is applied in the indirect tire pressure monitoring system but instead of detecting pressure of the tire by using pressure sensor, the radius of the wheel is the basis if the tire is in

proper condition.

Indirect Tire Pressure Monitoring System

Indirect acting TPMS measures the "apparent" air pressure indirectly, by monitoring individual wheel rotational speeds, and other signals available outside the tire itself. Most indirect TPMS use the fact that an under-inflated tire has a slightly smaller diameter than a correctly inflated tire and therefore, has to rotate at a higher angular velocity to cover the same distance as a correctly inflated tire. Such TPMS cannot detect under inflation in all four tires simultaneously, since if all four tires lose the same amount of air the relative change will be zero. In the US the TREAD Act prevents the use of any TPM system which cannot simultaneously detect under inflation of any or all four tires.

Newer developments of indirect TPMS can also detect simultaneous under-inflation in all four tires; Thanks to vibration analysis of individual wheels or analysis of load shift effects during acceleration and/or cornering, however additional sensors add to the complexity and cost of this technology. A hybrid method requires adding one direct TPMS sensor to a single tire on a vehicle, thereby, eliminating the four equally low tires scenario.

Indirect TPMS is cheap and easy to implement since most modern vehicles

already have wheel speed sensors for anti-lock braking system, and electronic stability control system. Another advantage of this technology is that no maintenance of the TPMS is necessary.

A disadvantage of an indirect system, compared to direct, is also the periodic requirement for recalibration, creating 'unsafe' windows where low tire detection is unavailable. Recalibration must be started manually when tires are changed or re-inflated. Forgetting to perform this initialization can lead to potentially dangerous false-positive or false-negative alerts. Incorrect calibration by the user (such as calibration when one or more tires are under-inflated) can also cause unreliable operation. (*Tire Inflation, 2008* ***by Larry Carley***)

The Conceptual Framework

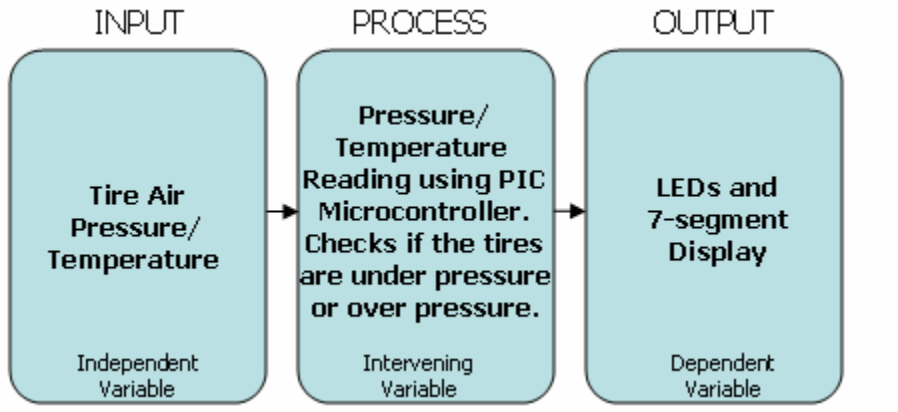

Figure 1.2 Conceptual Framework

Figure 1.2 shows the flow of the direct tire pressure monitoring system. The TPMS sensor/transmitter module measures the temperature and pressure of

the tire. After the values are acquired, it would be transmitted to the TPMS display/receiver module. The user would now determine if the tires are over pressured or under pressured.

Statement of the Problem

The main problem of this study is the bond between the tire pressure gauge and the LED. Specifically, this study seeks to answer the following

1. How will the user recognize if the tire has proper pressure and temperature?
2. Can the design acquire and display the tire pressure and temperature?
3. What would the system look like for the driver to view the results easier?
4. How will the system warn the user if there are some tire problems?

Objective of the Study

The Direct Tire Monitoring System has the following objectives:

1. Inform the driver on recognizing if his/her vehicle has correct tire pressure and temperature.
2. Acquire correct pressure and temperature of the tire to be displayed on the system.
3. Create a user-friendly display of pressure and temperature.
4. Provide an alert which will inform the driver that he/she has tire problems.

Significance of the Design

The Direct Tire Pressure Monitoring System is a new innovation for improving vehicle safety particularly with tire pressure. The system is very helpful in avoiding accidents caused by having a flat tire. Drivers could easily determine their vehicle's tire pressures. With this, they don't need to stop in the nearest gasoline station just to check their tires or stop by and check each tire with a pressure gauge. Properly maintained tires help with vehicle safety, performance and economy.

Scope and Delimitation

The Direct Tire Pressure Monitoring System has the following scopes:

1. The design is composed of five modules which are the: 4 TPMS sensor/transmitter module and a TPMS display/receiver module.
2. LEDs are provided for easier reading and each LED corresponds to the tires and alerts
3. In order for the design to operate, the vehicle must be on.
4. The design will check the pressure and temperature of each tire every 30 seconds.
5. The 7-segment display will output the temperature and pressure.
6. The reading will be considered as under inflated if the pressure is below 28 psi and over inflated if above 35 psi.

7. After the reading, the system will auto-activate its sleep mode.

The following are the limitations of the design:

1. The design is only applicable to 4-wheel vehicles weighing 4,500 kg.
2. The design is not applicable to motorcycles and trucks.
3. The design is not portable which can be easily transferred to other cars.
4. The user cannot select the only tire he/she wanted to check.
5. The checking of the pressure of each tire is continuous and it cannot be stopped.

Definition of terms

1. Ambient is outside air temperature. (*Encarta Encyclopedia (2007)*)
2. Apparent is appearing real or true based on evidence that may not be valid. (*Encarta Encyclopedia (2007)*)
3. Bourdon tube is a pressure sensing element constructed from a flattened tube, sealed at one end, twisted or curved. (*Newtonian Physics (2005)*)
4. Cold inflation pressure is the inflation pressure of tires before the car is driven and the tires warmed up. (*Newtonian Physics (2005)*)
5. Frequency is a measure of the number of occurrences of a repeating event per unit time. (*Encarta Encyclopedia (2007)*)

6. Friction is the force resisting the relative motion of two surfaces in contact or a surface in contact with a fluid (e.g. air on an aircraft or water in a pipe). It is not a fundamental force, as it is derived from electromagnetic forces between atoms and electrons, and so it cannot be calculated from first principles, but instead must be found empirically. (*Newtonian Physics (2005)*)
7. Glycerine is a chemical compound also commonly called glycerin or glycerol. It is a colorless, odorless, viscous liquid that is widely used in pharmaceutical formulations. (*Encarta Encyclopedia (2007)*)

8. Hardware is a general term that refers to the physical artifacts of a technology. (*Encarta Encyclopedia (2007)*)
9. Insinuation is synonymous with implication. (*Encarta Encyclopedia (2007)*)
10. LED (Light-Emitting Diode) is a semiconductor diode that emits light when an electrical current is applied in the forward direction of the device, as in the simple LED circuit. (*Encarta Encyclopedia (2007)*)
11. MHz (MegaHertz) is the basic unit of frequency in the International System of Units (SI), and is used worldwide in both general-purpose and scientific contexts. (*Encarta Encyclopedia (2007)*)
12. Microcontroller is a functional computer system-on-a-chip. It contains a

processor core, memory, and programmable input/output peripherals. (*Encarta Encyclopedia (2007)*)

13. Sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. (*Encarta Encyclopedia (2007)*)
14. Seven-segment display (abbreviation: "7-seg(ment) display"), less commonly known as a seven-segment indicator, is a form of electronic display device for displaying decimal numerals that is an alternative to the more complex dot-matrix displays. (*Encarta Encyclopedia (2007)*)
15. Placard is a sign or sign-like device attached to or hung from a vehicle to indicate information about the operator (of a vehicle) or the contents of the vehicle or building. (*Encarta Encyclopedia (2007)*)
16. Pressure is the force over an area applied to an object in a direction perpendicular to the surface. (*Encarta Encyclopedia (2007)*)
17. Program is a series of computer instructions that are designed to accomplish a task or achieve a particular result. (*Encarta Encyclopedia (2007)*)
18. Psi (Pounds per Square Inch) is a unit of pressure or of stress based on avoirdupois units. 1 psi (6.894757 kPa) : pascal (Pa) is the SI unit of pressure. (*Newtonian Physics (2005)*)
19. Temperature is a physical property of a system that underlies the

common notions of hot and cold; something that is hotter generally has the greater temperature. (*Encarta Encyclopedia (2007)*)

20. Tire-pressure gauge is a pressure gauge used to measure the pressure of tires on a vehicle. (*Encarta Encyclopedia (2007)*)
21. Traction is the power to grip or hold to a surface while moving without slipping. (*Encarta Encyclopedia (2007)*)
22. Transmitter is an electronic device which, usually with the aid of an antenna, propagates an electromagnetic signal such as radio, television, or other telecommunications. (*Encarta Encyclopedia (2007)*)
23. Threshold is synonymous with entrance. (*Encarta Encyclopedia (2007)*)

Chapter 2

METHODOLOGY

Research Design

The design methodology provides instructions and procedures on how to develop a tire pressure monitoring system. At first, the group conducted a research on previous projects and designs that have a relation to the proposal. From there, supplementary information were then gathered from books and internet resources. With the data on hand, the group was able to conceptualize the system's flow and design of the hardware and software.

Through a research, the group found out that the sensor module must be small enough so that the tire will not be unbalanced. With this information available, the group began searching for components that are light and compact but can deliver the need. This was an essential procedure since the project's objective is to monitor each tire.

Data Gathering

1. The group read articles and studies regarding safety and maintenance of tires which involves the tire's pressure.
2. After considering the factors that can affect the tire pressure and the stability of the wheel, the group researched for components that are compact but can still deliver the project requirements.

3. Selected components were then verified for usability and reliability through surveys done in the internet forums intended for technologically-inclined people and through the manufacturers' technical support.

Since the components needed for the design have a high price, the group carried out a prototyping design to ensure that the components will work fine and are compatible with each other.

Design Implementation (Software)

1. Brainstorming in how the system works.
2. Producing the flow of the system.
3. Creating the program to be embedded in the microcontrollers.
4. Simulating the program using OshonSoft PICSimulator IDE.
5. Verifying the output if it is accurate.
6. Making the necessary changes on the program after simulating.

Design Implementation (Hardware)

1. Creating the circuit diagram of the system and its connection based on the components datasheet.
2. Obtaining the components after verifying that the design of the hardware is running properly using Multisim IDE. Some components were bought overseas, mostly from Singapore, because they are not available in the Philippine market.

3. Creating the hardware of the system after burning the program in the microcontrollers.

To ensure that the driver will notice if there is a problem in the vehicle's tires, the group decided to use 7-segment displays for the actual reading and LEDs for the parameters. If a tire's pressure reading is out of the valid range, the LED designated for the tire will blink and a beeping sound is made.

To determine the design's accuracy and reliability, actual testing was done. The design's reading was tested against a digital tire pressure gauge to get the percentage error.

Design Testing

1. After creating implementing the design, the group installed the system in a vehicle.(See Appendix E for Installation Guide)
2. The design was then tested against a digital tire pressure gauge to check for system reliability and integrity. Detailed discussion is included in Chapter 3.

Design Procedure for Prototype Development

Hardware Design for Prototype Development

For the prototype development, two modules we built: the display module which shows the pressure reading and warning for the tire, and the sensor module which was placed inside the tire’s interior. Both modules were packed

inside a small metal container so that the components will not be flattened when installed. For the readings, a 3-digit 7-segment was used. LEDs are used to indicate the reading being displayed and for the warnings. Components for the prototype are listed on Table 2.1 and Table 2.2. Table 2.1 registers what is used in the Display module while Table 2.2 shows the components for the Sensor module.

List of Components

Quantity	Component	Description
1	PIC16F877	Microcontroller
5	LED	Display
1	3-digit 7-segment display	Display
1	RFRXD0420-I/LQ	RF receiver
1	TC4422	MOSFET Driver
1	RF Antenna	Antenna
1	SF0434BA02507S	SAW Filter

Table 2.1 Display Module components

Quantity	Component	Description
1	MS507	Pressure sensor
1	LM75	Temperature sensor
1	rfPIC12F675F	Microcontroller/ RF transmitter

Table 2.2 Sensor Module components

Circuit Diagrams

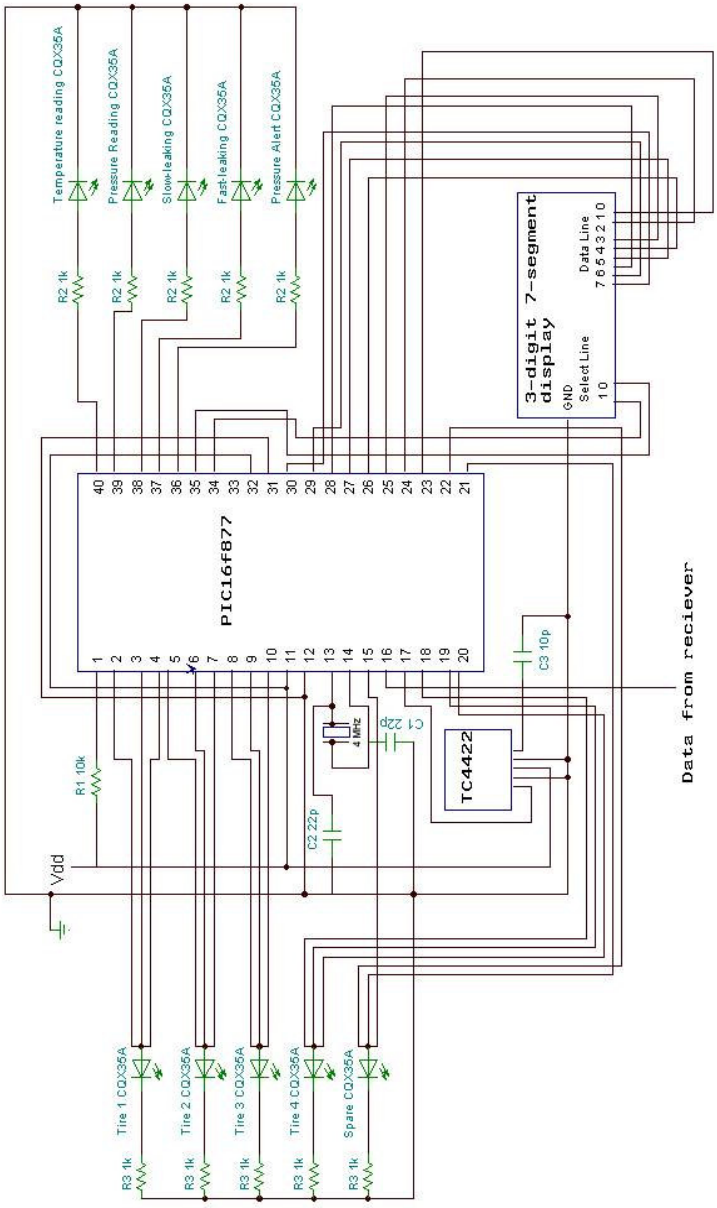

Figure 2.1 Display Module Circuit (User Interface)

Figure 2.1 illustrates the circuit for the prototype's Display module. The components are listed on Table 2.1.

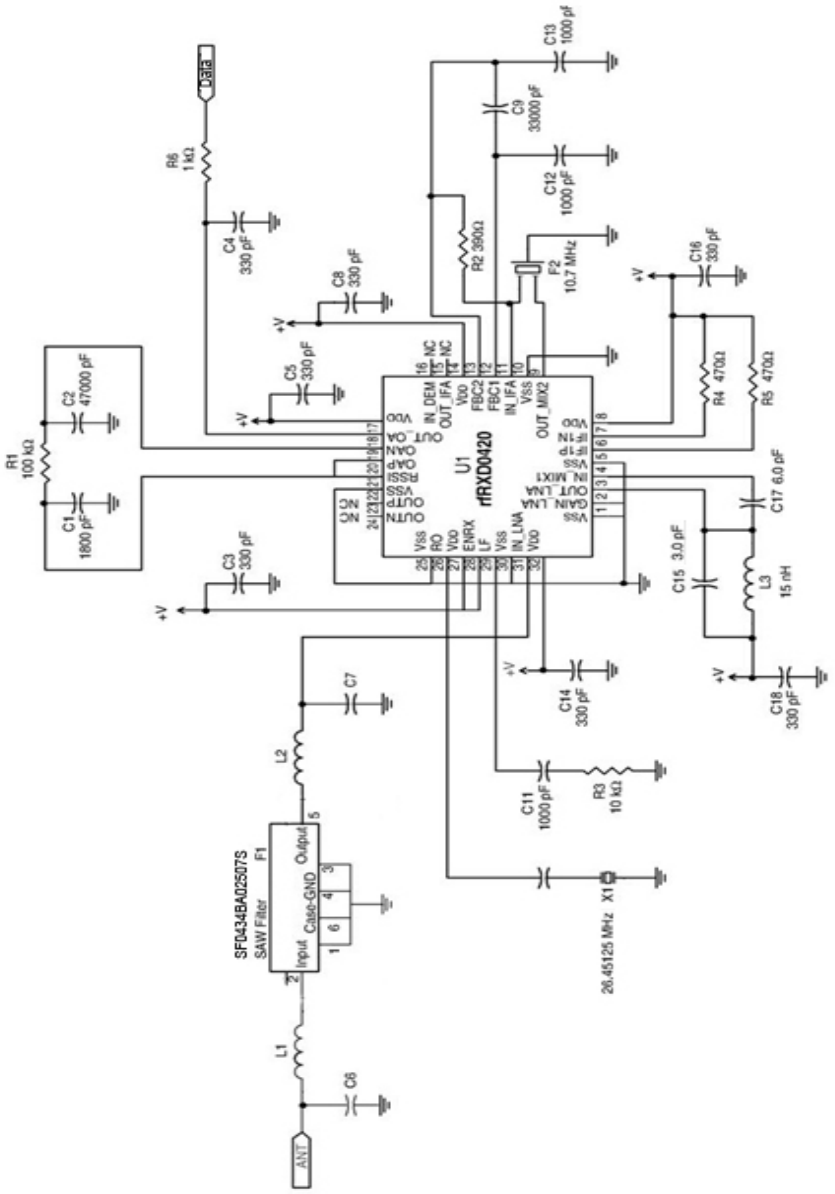

Figure 2.2 Display Module Circuit (RF Receiver Circuit)

Figure 2.2 is the illustration of the RF receiver module. The antenna should be located in the wheel mounted to ensure data integrity.

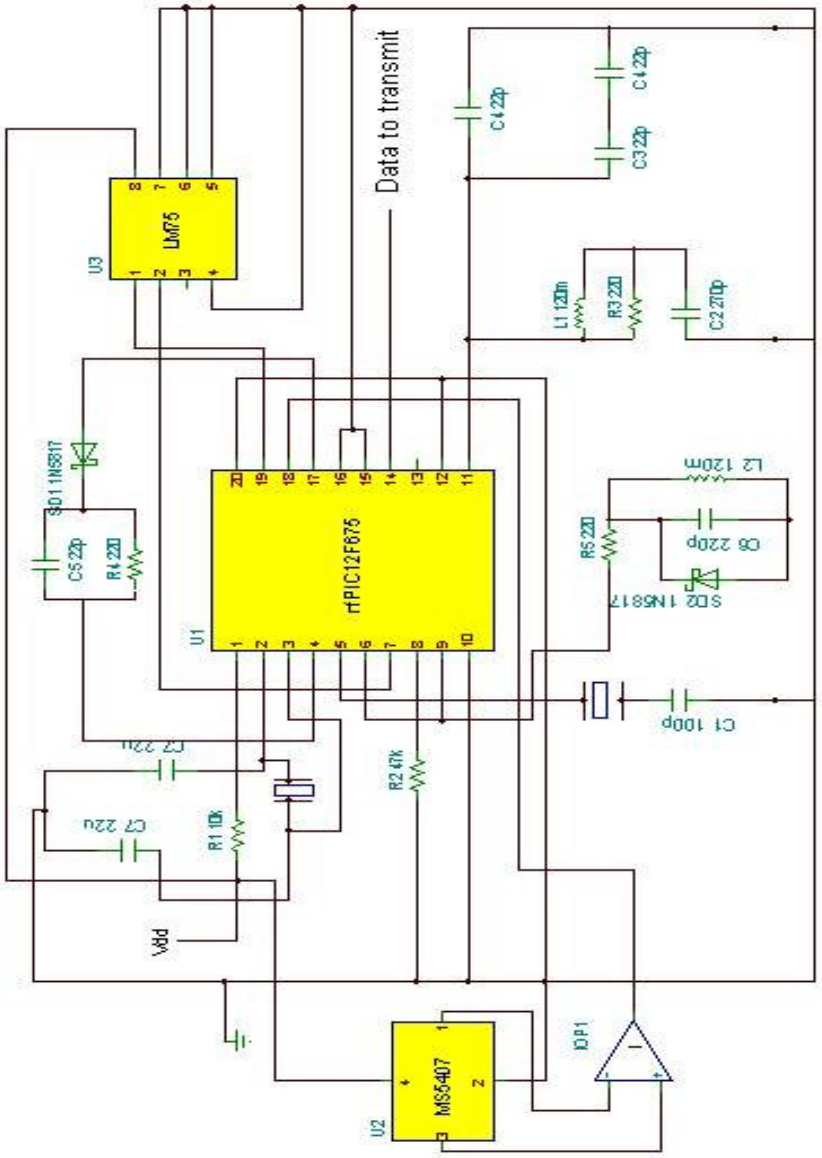

Figure 2.3 Tire Sensor Module Circuit

Figure 2.3 is the circuit for the Tire Sensor modules. Detailed component list is found in Table 2.2.

Software Design for Prototype Development

For the software, the group used C language to program the PIC16F877 and rfPIC12f675 microcontrollers. MPLAB IDE v7.60 and the plug-in PIC C were used to utilize the C language in our design.

For the pressure reading, the display module multiplies the pressure data the sensor module sent by 14.5 since the MS5401 pressure sensor measures the pressure in bars and not in psi. The conditions that were set in the display module sensor to determine if the tire is correctly inflated or is safe to use are the following:

- Pressure difference is not more than 1psi.
- If pressure difference is more then 1psi, temperature difference should be at least 10^{o} F. If temperature difference is not more than 10^{o} F, it enables slow-leaking.
- If pressure difference is more than 2psi and temperature difference is not more than 10^{o} F, it enables fast-leaking LED.
- If pressure is more than 35psi and lower than 28psi, it enables Pressure Alert LED.

Figure 2.4 shows the prototype's system flowchart and how the system operates.

System Flowchart for Prototype Development

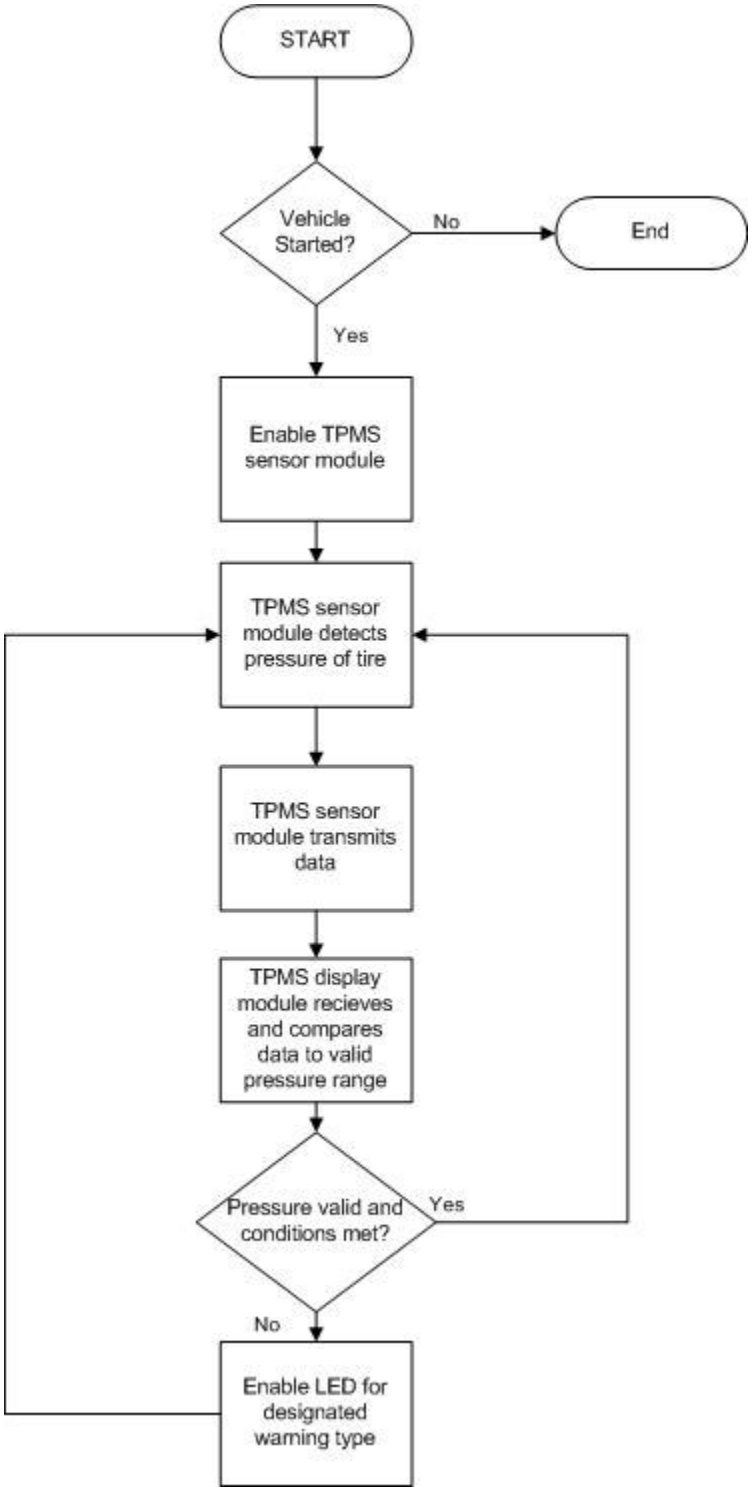

Figure 2.4 Flowchart for Prototype (Software)

Design Procedure for Actual Design

Hardware Design for Actual Design

The actual design has 6 modules: the display module from the prototype design, which was modified to accommodate new sensor readings and four new sensor modules, one for each of the active tire. Also, 5 LEDs (Tire 1, Tire 2, Tire 3, Tire 4, Spare tire) were added to the Display module to indicate what tire is being monitored. Tire position of the sensor in the vehicle is critical since the display module uses the tire id to enable the tire's designated LED. The positioning of the tires is identified on Figure 2.5.

Figure 2.5

The spare tire was used as a sample prototype before finalizing.

List of Components

For a more detailed list of components for the Display module and Sensor Module, see Table 2.1 and 2.2.

Software Design for Actual Design

The software of the actual design is the same as the prototype development. The only distinction of the program is the ID generated by each of the sensor modules and how the display modules identify what tire is being observed.

Each tire sensor module has a unique tire ID. This ID is used by the Display module to know what LED it should enable. The sensor module also sends a preamble, an 8 bit data to let the display module know that the one sending the data is a tire sensor module. After sending the preamble, the tire ID is sent, and then the pressure reading and the temperature reading follow.

The system's flowchart is presented in Figure 2.6. It shows how the actual design operates.

System Flowchart for Actual Design

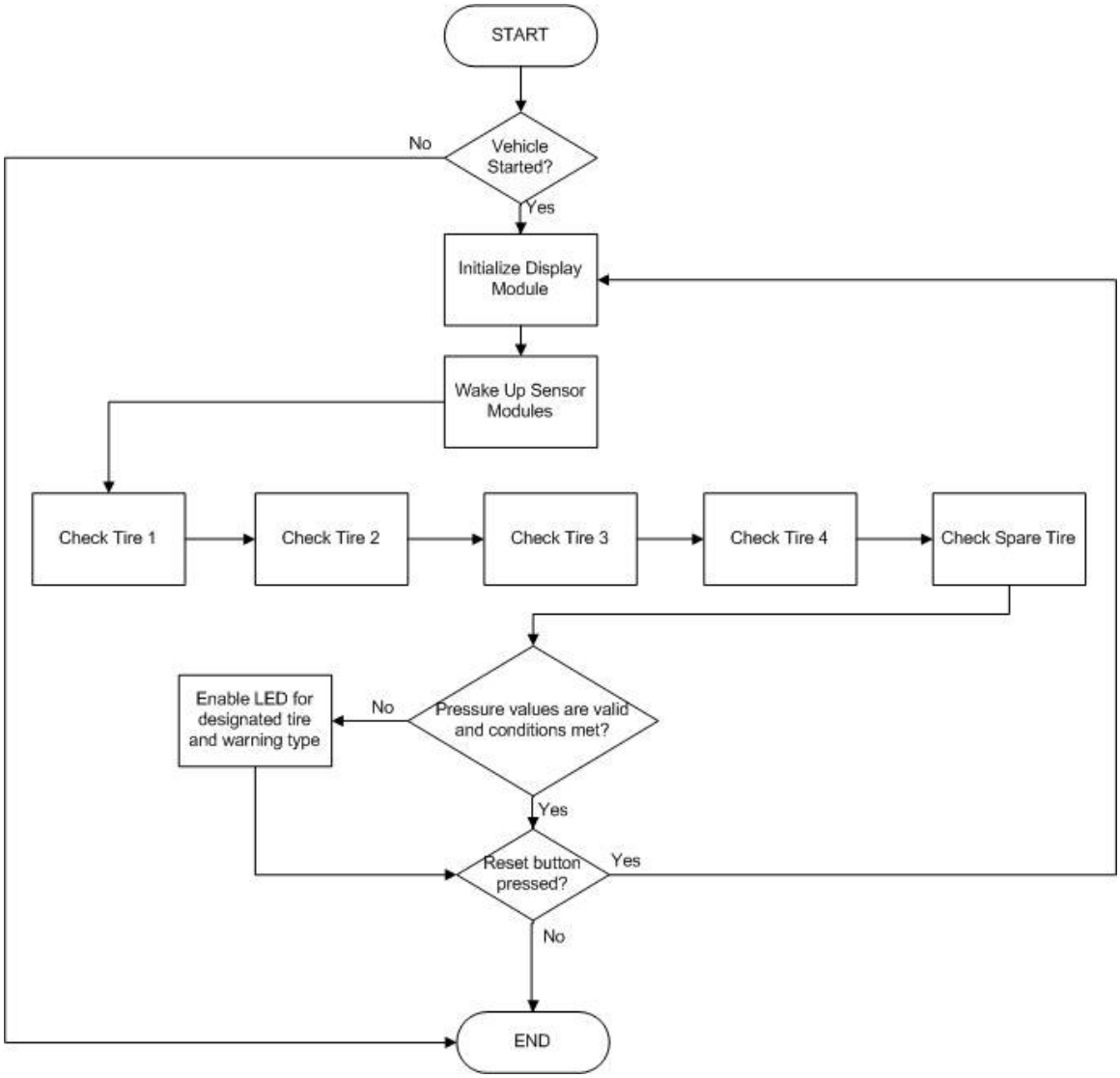

Figure 2.6 Flowchart for whole system

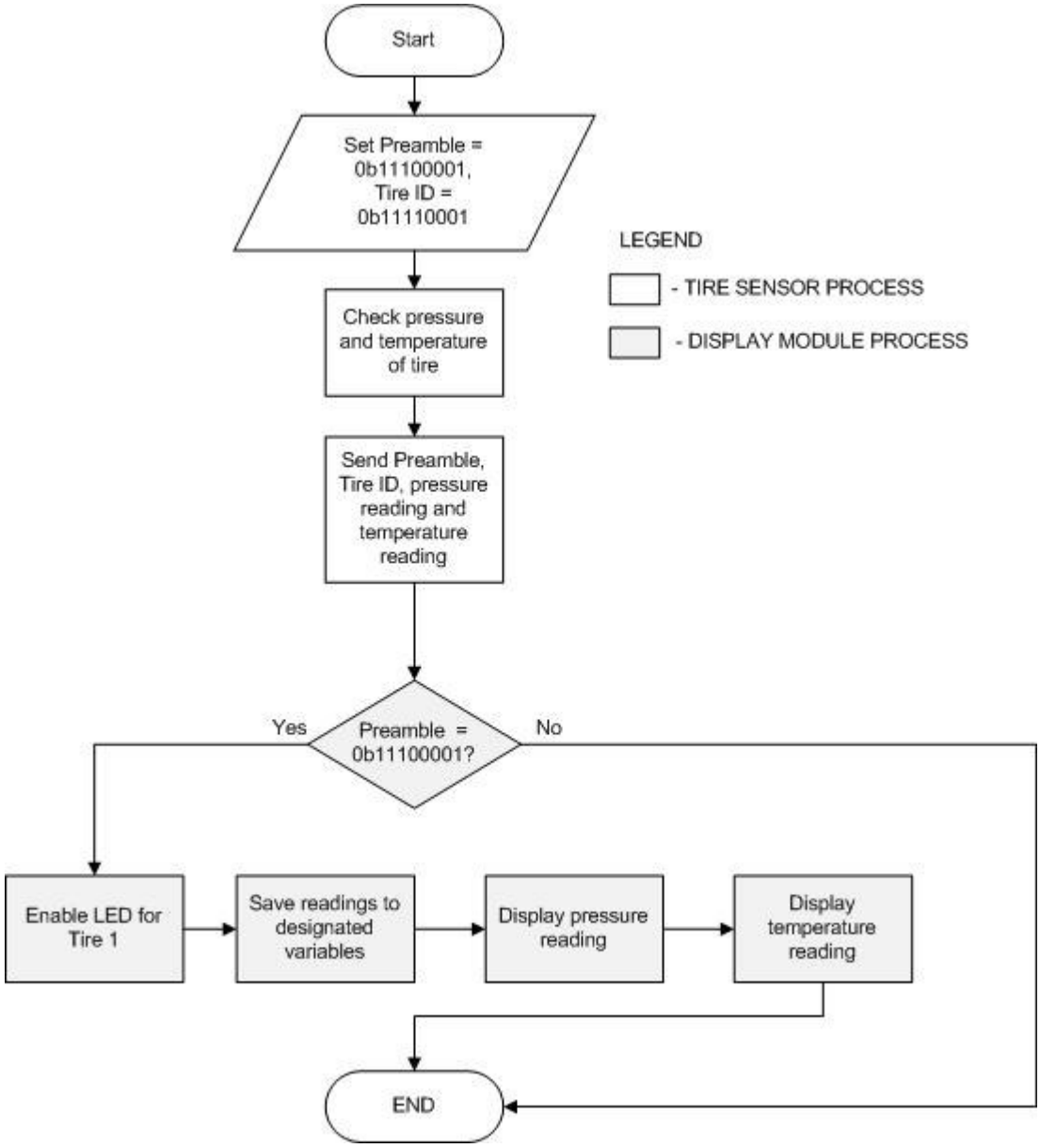

Figure 2.7 Flowchart for Check tire 1

Figure 2.7 illustrates how Tire sensor 1 is operating within the tire and how it passes the data. It also shows how Display module reads the data submitted and how it interprets it.

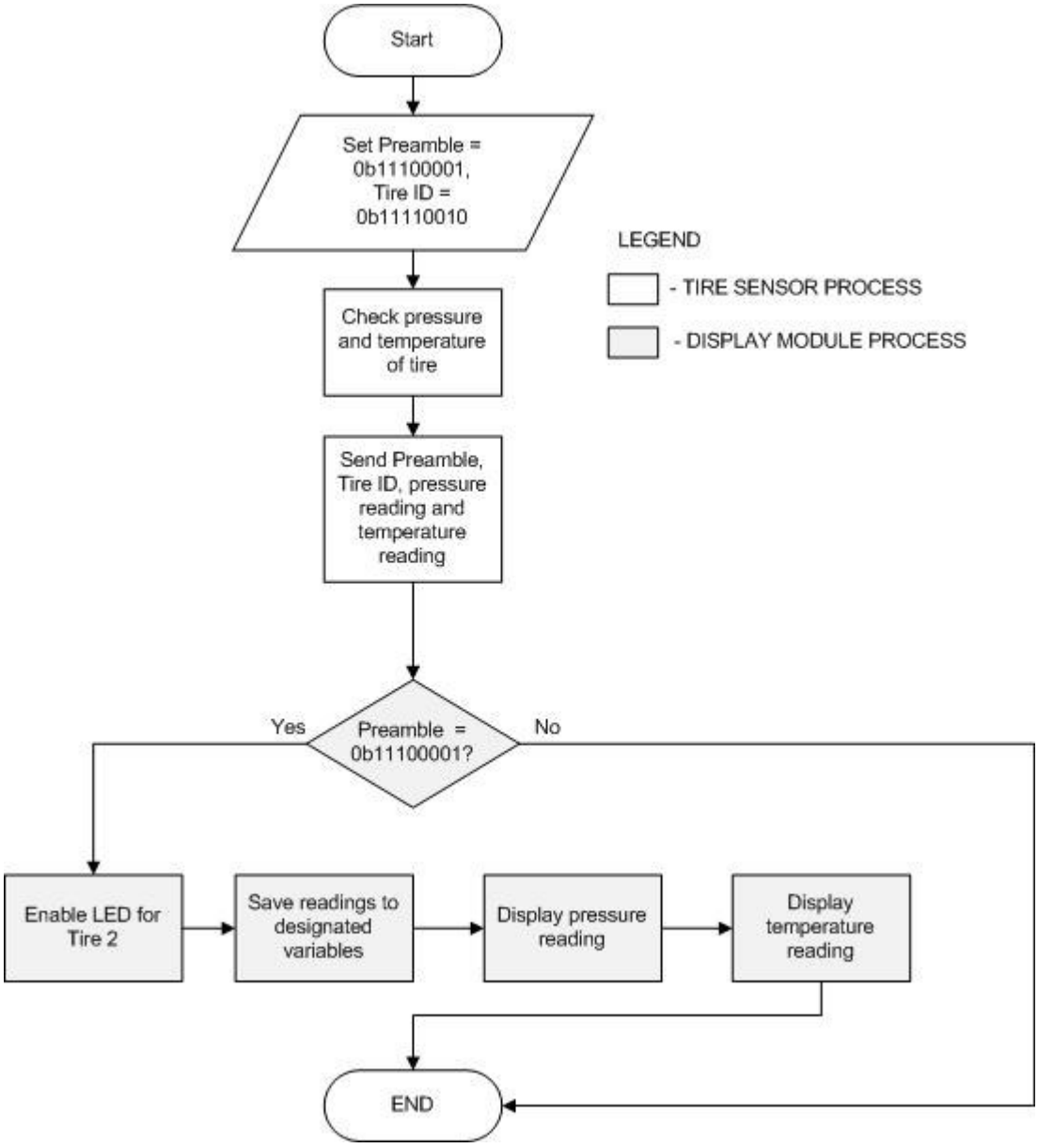

Figure 2.8 Flowchart for Check tire 2

Figure 2.8 demonstrates how Tire sensor 2 is working within the tire and how it passes the data. It also shows how Display module reads the data submitted and how it interprets it.

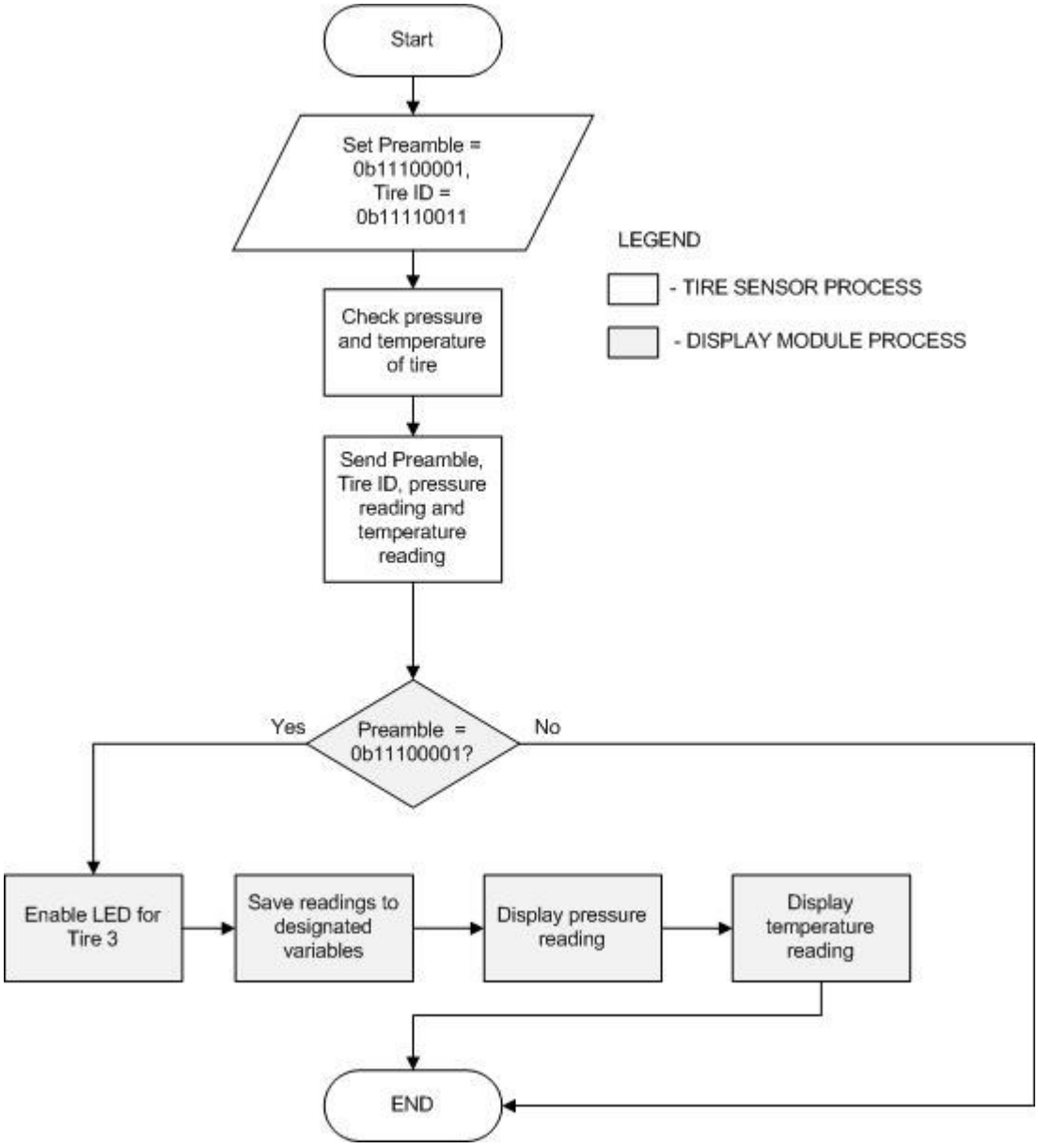

Figure 2.9 Flowchart for Check tire 3

Figure 2.9 displays how Tire sensor 3 is working within the tire and how it passes the data. It also shows how Display module reads the data submitted and how it interprets it.

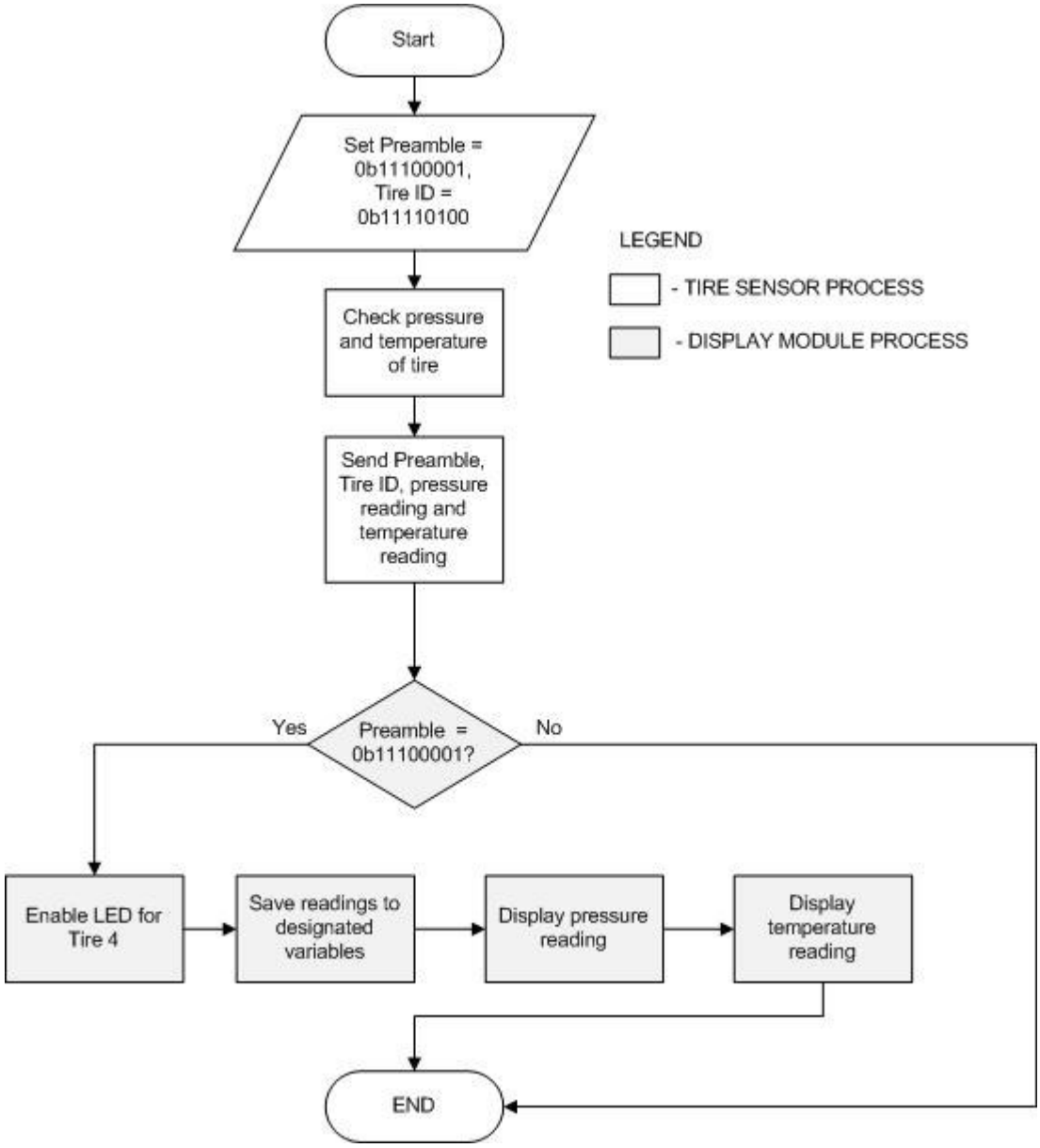

Figure 2.10 Flowchart for Check tire 4

Figure 2.10 demonstrates how Tire sensor 4 is working within the tire and how it passes the data. It also shows how Display module reads the data submitted and how it interprets it.

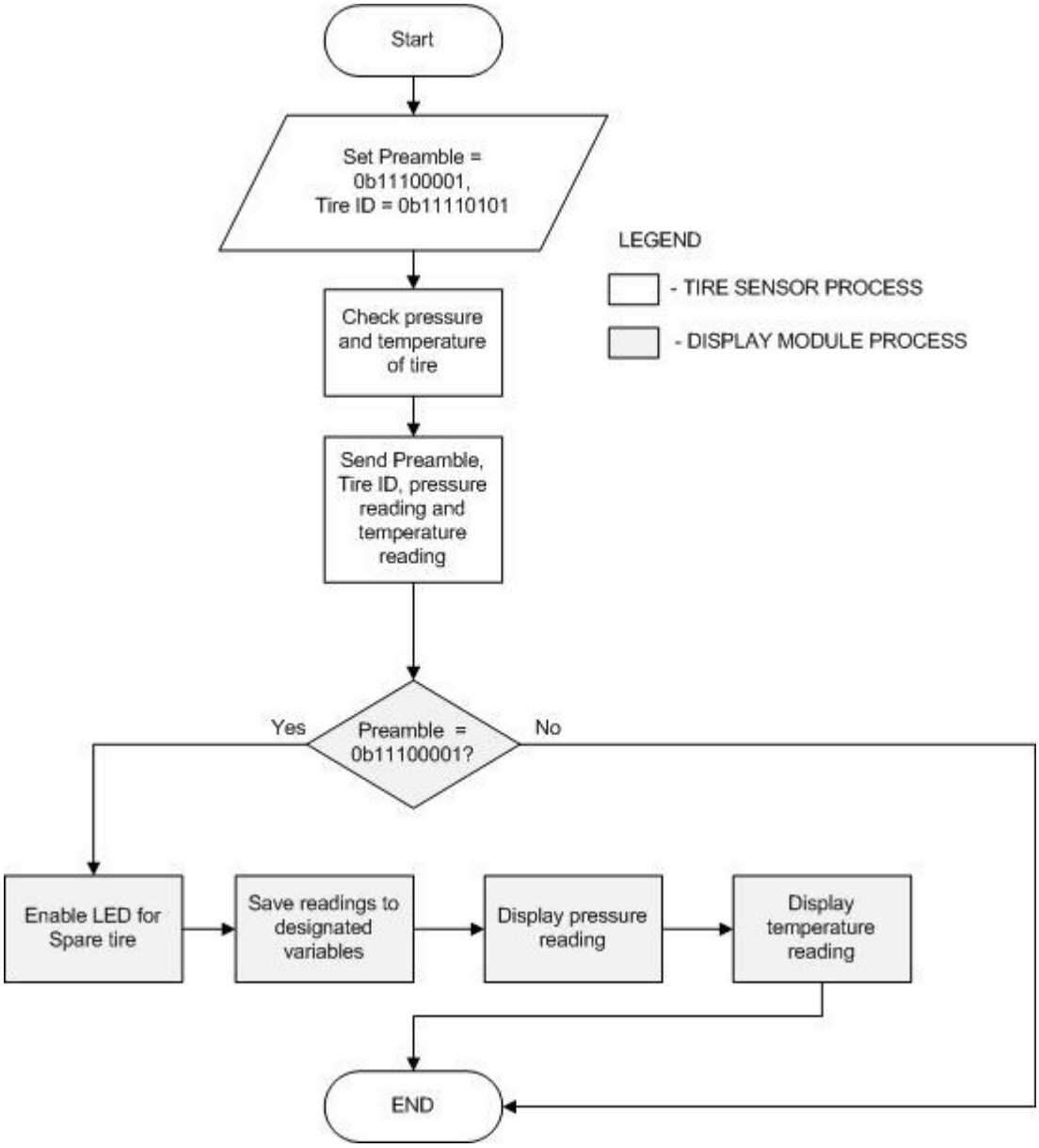

Figure 2.11 Flowchart for Check Spare Tire

Figure 2.11 exhibits how the spare tire sensor is working within the tire and how it passes the data. It also shows how Display module reads the data submitted and how it interprets it.

PROTOTYPE DEVELOPMENT

Finding the components was the first thing the group did. The rfpic12f675f and the RFRXD0420-I/LQ were ordered online. The group decided to use the RFPIC microcontroller for the tire sensor modules since it already has an attached RF transmitter. Using this microcontroller will make the design compact since it does not need another device. Second, the rfPIC12F675 also has an internal comparator which plays a vital role in decoding the information from the LF link. Lastly, the rfPIC12F675 features a 10-bit Analog-to-Digital converter, allowing the group to use analog output pressure sensors. For the temperature and pressure sensor, one of the group members went to Singapore because delivery of items will take a long time if bought online. The microcontroller used for the display module is available here in the country.

After collecting all the necessary components, the group made the software for the design. The group used MPLAB IDE to program the microcontrollers. To test the program without having to embed the software in the microcontrollers, the group used OshonSoft PICSimulator.

The frequency used for transmitting the data is 434 MHz ASK. To get this frequency, the crystal that was attached to the rfpic's pin 5 (see Appendix D for pin configurations) is 13.52 MHz, which is available in the Philippine market.

For the prototype development, the design was installed in a vehicle to test and to confirm that the prototype is working properly. Since the prototype's

design consists of only one tire sensor module, it was installed on the upper-left wheel position and the display module tapped on the accessories jack of the vehicle. The wiring for the RF receiver antenna was tied to the vehicles chassis to avoid tangling with the tires. The antenna is positioned in the wheel chamber so that the RF signal will not go through many obstructions.

The power supply of the display module is connected on the vehicle's accessories connection. Power is acquired from the vehicle's battery.

Chapter 3

TESTING, PRESENTATION AND INTERPRETATION OF DATA

The testing of the design is composed of 2 parts; the first part was done on August 28, 2008, between 3:30 pm to 6:20 pm. The design team started the route from Mapua Institute of Technology to Cavite and back to the Institute. The second part was done when the vehicle is at rest and the design team observes the output of the design.

Testing Procedure for Part 1:

1. Measure the pressure and temperature of each tire starting from Tire 1, Tire 2, Tire 3 and Tire 4 using the design.
2. Measure the pressure of each tire using the digital tire gauge.
3. Using the odometer, measure the distance travelled by the vehicle and reset it for the next measurement.
4. The vehicle will have a pit stop and steps 1 to 3 will be repeated until 5 pit stops have been completed.

Testing Process for Part 2:

1. Measure the initial tire pressure using the design.
2. Using a digital tire gauge, measure the tire pressure for comparison.
3. Inflate or deflate the tire with 1 psi up to 5 psi.
4. Jot down the results and observe the output for each interval.

Here are the following data gathered during the testing process:

Part 1:

Pressure

Trial	Distance	Measurement from a digital tire gauge	Measurement from the design	Difference	Percentage Error
1	0 km	32.5 psi	32.6 psi	0.1	0.31%
2	8.3 km	33.5 psi	33.0 psi	0.5	1.49 %
3	11.2 km	33.5 psi	33.4 psi	0.1	0.30 %
4	13.5 km	34.0 psi	33.4 psi	0.6	1.76 %
5	14.2 km	32.5 psi	33.0 psi	0.5	1.54 %
				Average	1.08 %

Table 3.1 Pressure of Tire 1

Table 3.1 is the tabulated representation of the measurement of pressure using a digital tire gauge and the design. This is the first tire to be measured and this tire is the one located at the upper left side of the vehicle. The result shows that the pressures from trials 1 to 4 are increasing but on trial 5, the pressure decreased.

Trial	Distance	Measurement from a digital tire gauge	Measurement from the design	Difference	Percentage Error
1	0 km	31.5 psi	31.9 psi	0.4	1.27%
2	8.3 km	34.5 psi	32.6 psi	1.9	5.50 %
3	11.2 km	33.0 psi	32.6 psi	0.4	1.21 %
4	13.5 km	32.5 psi	32.6 psi	0.1	0.31 %
5	14.2 km	32.0 psi	32.6 psi	0.6	1.90 %
				Average	2.04 %

Table 3.2 Pressure of Tire 2

The next table, Table 3.2, is for the second tire to be measured. In this table, the measurement of pressure was increasing from trial 1 to 4 but has a

minor decrease at the last trial.

Trial	Distance	Measurement from a digital tire gauge	Measurement from the design	Difference	Percentage Error
1	0 km	33.5 psi	33.7 psi	0.2	0.60%
2	8.3 km	34.5 psi	34.4 psi	0.1	0.29 %
3	11.2 km	35.0 psi	34.8 psi	0.2	0.57 %
4	13.5 km	35.0 psi	34.8 psi	0.2	0.57 %
5	14.2 km	34.5 psi	34.4 psi	0.1	0.29 %
				Average	0.46 %

Table 3.3 Pressure of Tire 3

The pressure measured using a digital tire gauge and the design in Tire 3 corresponds to Table 3.3. This tire is positioned to the lower right side of the car. Again, the measurements are rising but when the measurement for the last trial has been made, the pressure was reduced.

Trial	Distance	Measurement from a digital tire gauge	Measurement from the design	Difference	Percentage Error
1	0 km	32.5 psi	33.0 psi	0.5	1.53 %
2	8.3 km	33.0 psi	33.7 psi	0.7	2.12 %
3	11.2 km	35.0 psi	34.4 psi	0.6	1.71 %
4	13.5 km	34.5 psi	34.1 psi	0.4	1.15 %
5	14.2 km	33.0 psi	33.4 psi	0.4	1.21 %
				Average	1.54 %

Table 3.4 Pressure of Tire 4

Lastly, Table 3.4 is for the measurement of pressure for Tire 4 which is the last tire to be measured. The outcome of this table is almost the same on Table 3.1 to 3.4 because the pressure on the first 4 trials was increasing but the last trial was decreased.

Temperature

Trial	Distance	Measurement from the design
1	0 km	46˚C
2	8.3 km	45˚C
3	11.2 km	47˚C
4	13.5 km	49˚C
5	14.2 km	47˚C

Table 3.5 Temperature of Tire 1

Table 3.5 shows the temperature measured by the design on the Tire 1. Its temperature will also be the first one to be measured.

Trial	Distance	Measurement from the design
1	0 km	44˚C
2	8.3 km	45˚C
3	11.2 km	47˚C
4	13.5 km	50˚C
5	14.2 km	48˚C

Table 3.6 Temperature of Tire 2

After that, the temperature to be considered will be for Tire 2 and it is presented on Table 3.6 along with its corresponding distance.

Trial	Distance	Measurement from the design
1	0 km	41˚C
2	8.3 km	42˚C
3	11.2 km	44˚C
4	13.5 km	47˚C
5	14.2 km	44˚C

Table 3.7 Temperature of Tire 3

Table 3.7 is provided for the temperature reading in Tire 3 and like in the other readings, the temperature decreased in the last trial.

Trial	Distance	Measurement from the design
1	0 km	41˚C
2	8.3 km	43˚C
3	11.2 km	45˚C
4	13.5 km	45˚C
5	14.2 km	42˚C

Table 3.8 Temperature of Tire 4

The last tire to be measured is Tire 4 and its temperature measurement according to the design is on Table 3.8.

From the data gathered, it shows that the pressure and temperature increase from trial 1 to trial 4 but decrease on the last trial. A reason for the decrease in pressure and temperature is because the pressure is directly proportional with the temperature (according to the Ideal Law of Gasses) and the design team arrived at the last pit stop at 6:20 PM so the environmental temperature is much colder compared to the last 4 pit stops. A possibility for the slight fluctuation in the reading can be caused by the digital tire gauge. As the tire is measured using the tire gauge, a small amount of pressure comes out of the tire. Then, the design team also computes for the percentage error and the computation for the average percentage error resulted to a 1.28%.

Here is the computation for the percentage error and reliability:

Percentage Error = $\frac{|\text{Measured result} - \text{Actual Result}|}{\text{Actual Result}} \times 100\%$

Average = $\frac{\text{PError 1} + \text{PError 2} + \text{PError 3} + \text{PError 4} + \text{PError 5}}{5}$

Average Percentage Error = $\frac{1.08\ \% + 2.04\ \% + 0.46\% + 1.54\%}{4}$

= 1.28 %

Percentage of Reliability = 100 % - 1.28 %

= 98.72 %

So we can conclude that the design is 98.72 % reliable according to the data gathered and the testing done.

Part 2:

Trial	Applied Pressure	Test tire using the design at 43˚C	Test tire using a digital tire gauge at 43˚C	Display
1	(initial) 31.2 psi	31.2 psi	31.4 psi	Alerts OFF
2	+1 psi	32.5 psi	32.3 psi	Alerts OFF
3	+2 psi	33.2 psi	33.4 psi	Alerts OFF
4	+3 psi	34.2 psi	34.5 psi	Alerts OFF
5	+4 psi	34.9 psi	35.0 psi	Alerts OFF
6	+5 psi	35.6 psi	35.8 psi	Pressure alert ON

Table 3.9 Increasing Pressure

Table 3.9 represents the measured temperature on Tire 1, which serves as a test tire. The initial pressure in it is 31. 2 psi and it is inflated up to 5 trials to test if the alerts displayed are correct. When the pressure reached 35+, the Pressure Alert LED turned ON because the measured pressure is already out of range.

Trial	Applied Pressure	Test tire using the design at 43˚C	Test tire using a digital tire gauge at 43˚C	Display
1	(initial) 31.2 psi	31.2 psi	31.4 psi	Alerts OFF
2	-1 psi	29.1 psi	29.3 psi	Alerts OFF
3	-2 psi	28.2 psi	28.0 psi	Slow Leaking ON
4	-3 psi	27.5 psi	27.2 psi	Pressure alert ON
5	-4 psi	26.3 psi	25.9 psi	Pressure alert ON
6	-5 psi	25.1 psi	24.9 psi	Pressure alert ON

Table 3.10 Decreasing Pressure

For the last testing process, decreasing the pressure of the test tire and observing its alerts are done in Table 3.10. Its initial pressure value is also 31.2 psi. When the pressure decreases by 2 psi, the slow leaking LED will turn on. If the difference is more than 2 psi, the fast leaking LED will turn on and if the pressure is out of range (28 psi – 35 psi), the Pressure Alert LED will turn on.

From these conditions, the test conducted displays the expected status.

Chapter 4

CONCLUSION AND RECOMMENDATION

Conclusion

Direct tire pressure monitoring system was accomplished with the design presented here. The design is very helpful to every driver for it can monitor the pressure of each tire. The measured pressure will be shown to the display module for the drivers' convenience. With this, they don't need to stop in the nearest gasoline station just to check if their tires are doing well or stop by and check each tire with a pressure gauge. Drivers would have no difficulty in using the system because it is very user friendly and proper labels are implemented for easier understanding. The temperature sensors are also added to the design to give the drivers more information of the tire's temperature condition.

The design provides alerts for the drivers if tire problems occur. The color LEDs provide the drivers with an instant visual summation of the entire systems condition. If the tire begins to sway from normal parameters the LED color will change and allow the driver to know that a situation might be arising that needs attention. If the colour of the LED was to go to red then the driver would be informed that an improper condition was developing that could cause a hazardous or even deadly situation if it isn't quickly taken care of.

Thus, the Direct Tire Pressure Monitoring System can really be a big help to the drivers' convenience and safety because of its features.

Recommendations

The design team would like to recommend the following:

1. The system would be allied with a car manufacturer. In this approach, the system would be integrated to the product of the car manufacturer and this will produce income.
2. The system would be implemented to any kind of vehicles like multiple wheeled trucks, motorcycles and etc.
3. The display would be more interactive by replacing the 7-segment screen with colored graphics.
4. Additional features can also be added to the system like checking a specific tire's pressure.
5. Additional studies can also be conducted if there would be an effect to the balance of the tire if a sensor will be installed.

BIBLIOGRAPHY

University Physics with Modern Physics with Mastering Physics, 2004 (9th Edition) (MasteringPhysics Series) *by* Hugh D. Young, Roger A. Freedman

The Physics Factbook , An Encyclopedia of Scientific Essays 2007 *by Brian Marino*

Tire Inflation, 2008 *by Larry Carley*

Vibration and Waves, 2005 *by Benjamin Crowell*

Newtonian Physics, 2005 *by Benjamin Crowell*

Electricity and Magnetism, 2005 *by Benjamin Crowell*